A Computer-Based Comparative Performance Analysis of QPSK and 4-QAM Schemes in Fading Channels

1B. O. Omijeh and 2 0.Sukubo
1Department of Electronic and Computer Engineering
2Centre for Information and Telecommunications Engineering University of Port Harcourt, Nigeria
E-mail-address: omijehb@yahoo.com (B. O. Omijeh)

ABSTRACT: Amongst the industry trend of modulation schemes are the QPSK and QAM schemes. The 4QAM scheme is one of the categories of QAMs, and is an equivalent of the QPSK scheme in terms of number of information bits transmitted per symbol. In this research, not only are the two schemes compared in Rayleigh and Rician fading environment, comparison was also made to find out the BER performance differences of each scheme in the fading channels by applying SNR/BER as key performance indicator. With a design modeled in Simulink for this purpose, various instances of simulations were run and the resulting values of SNR/BER over different time period recorded for QPSK and 4QAM in the fading channels. By ensuring proper signal alignment and comparing the experimental product of SNR and BER with the theoretical expression SNR x BER = 1, the data set obtained and thus, the results are considered reliable. Findings show that 4QAM is generally a better modulation scheme but, is preferable in Rayleigh fading channel at the cost of transmission stability. It was also established that QPSK is an ideal choice in Rician environment than it is in Rayleigh fading environment

Key Words: Quadrature Phase Shift Keying (QPSK), 4-Quadrature Amplitude Modulation (4QAM), Signal to Noise Ratio (SNR), Bit Error Rate (BER), Line of Sight (LOS), Error Rate Calculation (ERC), Rayleigh and Rician fading channels

1. INTRODUCTION

Quadrature Phase Shift Keying (QPSK) and 4-Quadrature Amplitude Modulation (4QAM) are two similar modulation schemes. Both are similar in number of information bit transmittable per symbol; meaning these modulation schemes are both capable of conveying 2 bits information per symbol.

In a typical transmission system, the messages conveyed from transmitter to receiver comprise the direct path component, and the environment imparted component. The environment imparted components are referred to as the multipath components; meaning that these components, on like the direct path component with clear Loss of Sight (LOS) between transmitter and receiver, are environment influenced by reflection, refraction and scatter. This causes the signals to take different paths that may not all have a clearly defined LOS between the transmitter and the receiver. Signals therefore arrive at the receiver at different times owing to these interferences and noise. The resultant effect on the transmission system is poor quality reception at the receiver. This effect on the transmitted signal is called fading. The carrier wave that picks up these distorted message signals in the form of wave itself, are themselves modulated in terms of their amplitude, frequency or phase.

QPSK and 4QAM are some examples of modulation schemes that can be used to achieve this. The performance of a telecommunication system or digital receiver is a measure of the noise and interferences inherent in its transmission, and is described in terms of Signal to Noise Ratio (SNR) and Bit Error Rate (BER).

2. RELATED WORKS

The QAM scheme is a modern modulation scheme that functions by combining amplitude and phase modulation. The parameters of the carrier wave modulated in QAM systems are actually the amplitude and phase at a go. QAM is the state of the arts scheme that has its transmittable information bits split into two equal parts with each part modulating an independent carrier wave [1].Both carrier waves are separated from each other by a phase of 90 degrees. In the QPSK scheme, only the phase of the carrier wave is modulated by the binary data (message signal) while the amplitude remains unchanged. The 4QAM scheme is different from the QPSK scheme in that its binary data modulates both the amplitude and phase of its carrier signal. It is therefore more difficult to demodulate 4QAM modulated schemes in the presence of noise as it is with all amplitude modulation schemes like ASK, QAMs etc [2] Thus, the 4QAM scheme is more noise prone, and may require higher signal power (SNR) to perform as such. QPSK and 4QAM modulation schemes can be applied in wireless and mobile communication, fiber optics, and DVB transmission.

Using BER and SNR indicators and sampling of N = 1000 at a Doppler shift of 100Hz, Rashmi et al (2011) working on the Performance Analysis of Different M-ray Modulation Techniques in Cellular Mobile Communication [3] concluded that QPSK is a better modulation scheme than 4QAM scheme in Rayleigh fading channel i.e. for same SNR. The research shows that as the order of PSK or QAM increases, the probability of error increases.

[4] also did similar work by comparing BER performance of different modulation schemes with OFDM multiplexing in AWGN, Rayleigh, Rician fading channels, and Nakagami-m. Reports from the graphs plotted (BER against SNR) shows that for every instance of simulation same SNR was used to test the BER performances for all channels. Again, the QPSK scheme offers a lower BER than 4QAM.

A paper by [5] on the BER analysis of WIMAX (Worldwide Interoperability for Microwave Access) standard in fading channels stipulated that, for an entire range of given SNR, QPSK modulated signals performs better in Rician fading environment than in Rayleigh fading environment. The paper compared the BER analysis of BPSK, QPSK, 16 QAM, 64 QAM in Rayleigh and Rician fading environment.

According to [6] the QAM scheme delivers a very low BER for the same SNR in Rayleigh fading channels than in Rician channels. This, they achieve in Simulink using signal trajectory, eye diagram, and discrete scatter plot blocks.

The variables they used were SNR, and Rician Factor (for Rician Channel).

Each time SNR is used to measure the BER produced for some given modulation schemes or sets of modulation schemes, the comparative analysis result may not be the same with a case where BER values are taken over a given period of time, using the same data set [7] .

Signal to Noise Ratio (SNR) and Bit Error Rate (BER) are used as performance indicators in analogue/digital transmission. SNR is used more in analogue transmission while BER is used to refer to digital transmission. BER in telecommunication transmission is described as the percentage of bits that have errors relative to the total number of bits received in a transmission, and is expressed numerically as ten to a negative power [8]. Thus, for a given amount of data transmitted, it may just be the right decision to reduce the data rate in order to improve on transmission time. Reducing the data rate simply may reduce the very high BER.

[9] defined BER as the rate at which error occur in a transmission system during a studied interval of time, and interpreted it as expressed below.

$$BER = \frac{number\ of\ errors}{total\ number\ of\ bits\ sent} \quad (1)$$

The SNR is mathematically expressed as;

$$SNR = Psignal/Pnoise \quad (2)$$

Where Psignal =Signal Power, and Pnoise = Noise Power

SNR/BER Relationship:

SNR is inversely related to BER, and is the analogue equivalent of the BER. As the SNR increases for any given transmission system, the BER decreases; meaning a transmission system with a good performance is one likely with a low BER.

$$SNR\ x\ BER = 1 \quad (3)$$

The theoretical expression in (3) may be used in practice to measure the integrity and reliability of values of SNR/BER recorded for performance evaluation and analysis of transmission systems.

FADING

[10] described fading as the fluctuation in signal strength as it gets to the receiver. The multipath components are reflected, refracted and scattered by the environment, and arrive the receiver shifted in amplitude, frequency and phase with respect to the direct path component." The overall effect of this is that intended message by sender may not be exact message the receiver gets in terms of quality. There are two types of fading channels –Rayleigh and Rician. Fading channels depicts the transmission challenges that could be caused when transmitted signals are reflected, refracted and (or) scattered by tall buildings and trees, mountains etc. It is typical but not restricted to an urban environment.

Rayleigh Versus Rician Fading Channel

When signals follow multipath as a result of environment based impact of building, trees, and even suspended water droplets, they are caused to collide. The effect of this collusion could cause some to assume a better path and the others, even a worse path. The resultant effect is that there may not be a single LOS path. [9] sees this as the cause of Rayleigh fading. They put it thus; “the effects of multipath embrace constructive and destructive interference, and the phase shifting of the signals.” An oddity of Rayleigh fading channel is the absence direct line of sight (LOS) path between the transmitter and the receiver. Unlike Rayleigh fading channel, in Rician fading channel, there is a dominant LOS path[11].

3.0 Matlab/Simulink –based Design Approach

Using Matlab/ Simulink tool blocks [12], the Model was designed as shown in Fig. 1; and the relevant configuration implemented as specified in Table 1. This Designed Model consist of four systems as designated as follows:

- System 1: QPSK scheme in Rayleigh fading channel
- System 2: QPSK scheme in Rician fading channel
- System 3: 4QAM scheme in Rayleigh fading channel
- System 4: 4QAM scheme in Rician fading channel

SNR/BER values are tested by comparing the delay between the transmitted and received signals for various instances of Simulation. The Correlated Window length value was configured to 200, and the signal delay output from the align signal block compared with it for every instance of simulation. There are two input ports into the align signal block (transmitted S1, received S2), and three output ports from it to the ERC (Error Rate Calculator) and delay output block (transmitted S1, received S2 and delay value S3). In order to align the transmitted and received signals for effective Error Rate Calculation (ERC), the received delay output value is used by the align signal block to delay signals inputted into port S1 (transmitted signal port). This is done for every simulation, and the resulting values of SNR/BER over different time period recorded for QPSK and 4QAM in both fading channels.

The computed delay value from the align signal block was always accepted for delay values less than or equal to 75% of the correlated window length of 200. In any instance of simulation where they were more, the transmitted signal was inputted into port S2 whereas the received signal was inputted into S1 of the align signal block, and the simulation re-run for the appropriate delay value which should be less than or equal to 150. This is done to get the signals aligned at all times for correct BER values by the ERC. Delay value greater than 150 implies that the transmitted signal is delayed instead of the received signal for that particular instance; hence the swap of ports. Each instance of simulation was run for not less than 3 times to ensure the delay values from the align signal blocks were constant for a true BER values. At every such simulation the SNR values were also observe to ensure stability.

The experimental SNR and BER values were multiplied for each simulation and the resulting values were recorded as a measure to comparing with the theoretical value as defined by the expression in equation 3. In order to determine the integrity and reliability of the data set obtained for the BER performance analysis of the modulation schemes considered, the experimental averages of the recorded multiples of SNR and BER were determined for both fading channels, and the percentage error computed for each case in terms of eq.4.

$$\%Error = \frac{EValue - TValue}{TValue} \times 100 \quad \text{(eqn.4)}$$

Where Evalue = Experimental value, and Tvalue = Theoretical value.

4.0 RESULTS AND DISCUSSION

Table 1 shows the values for the SNR/BER performance of the QPSK and 4QAM schemes in Rayleigh fading channels. The data in the columns with the field names QPSK (BER x SNR) and 4QAM (BER x SNR) are imperative as it compares the outcome of the experimental multiples of the variables SNR and BER, with theory. The result shows an average of 1.0462 and 0.8802 for QPSK and 4QAM, with a percentage error of 4.62% and 11.98% respectively. Table 2 shows the SNR/BER outcome for both modulation schemes in Rician fading channel. Here, an average of 1.1629 and 0.9229 were recorded for QPSK and 4QAM, with percentage errors of 16.29% and 7.71% respectively. Table 4 is derived from tables 2 &

Various instances of the model were run over a time period ranging from T = 0.002 to 0.020 for QPSK & 4QAM in both Rayleigh and Rician Channels. The values are then tabularized and graphs plotted accordingly to analyse the system.

This simply means for a reliable data set, the product of the SNR and BER should yield an approximate value of 1 for every instance of simulation

3 to compare both schemes in Rayleigh and fading channel in terms of BER alone. The graphs for these tables are as shown in figures 3, 4 & 5. SNR and BER share an inverse relationship as expressed in eq.3. Figure 3 compares the SNR/BER performance of QPSK and 4QAM in Rayleigh fading channel, while figure 4 compares the SNR/BER performance of QPSK and 4QAM in Rician fading channel. Figure 5 is a BER performance excerpt from figures 3 & 4 that neatly represents and compares the performances of the modulation schemes for purpose of clarity. It compares the BER performances of:

- QPSK in Rayleigh and Rician fading channels
- 4QAM in Rayleigh and Rician fading channels, and

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- QPSK and 4QAM in Rayleigh and Rician
- fading channels

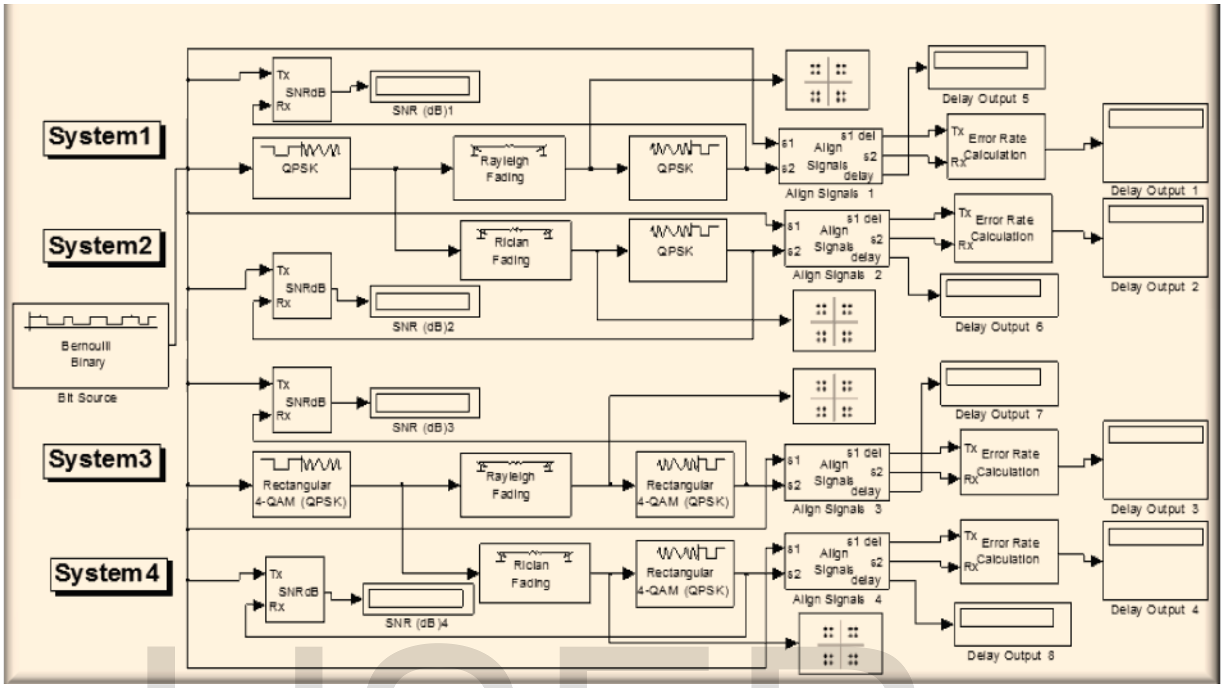


Figure 1: ***BER performance model for QPSK & 4QAM in fading channels***

Table 1*: QPSK & 4QAM PERFORMANCE IN RAYLEIGH CHANNEL*

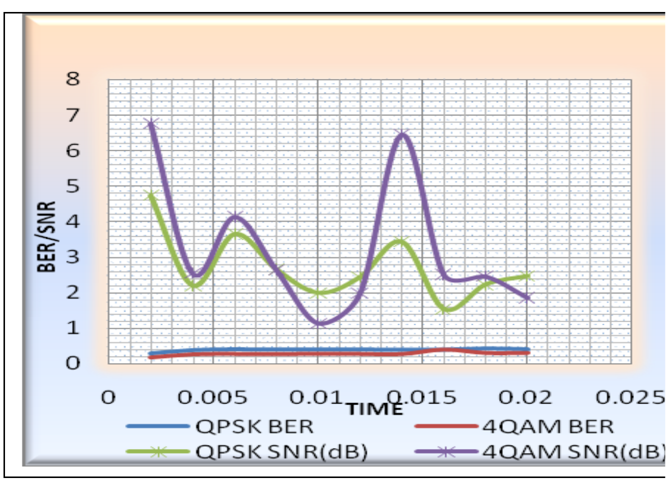
TIME	*QPSK BER*	*4QAM BER*	*QPSK SNR(dB)*	*4QAM SNR(dB)*	*QPSK(BER x SNR)*	*4QAM(BER x SNR)*
0.002	0.2902	0.1743	4.728	6.764	1.3720656	1.1789652
0.004	0.3847	0.2692	2.191	2.551	0.8428777	0.6867292
0.006	0.4073	0.2807	3.645	4.137	1.4846085	1.1612559
0.008	0.3984	0.2746	2.651	2.648	1.0561584	0.7271408
0.01	0.4051	0.2885	1.988	1.142	0.8053388	0.329467
0.012	0.3999	0.2815	2.432	1.985	0.9725568	0.5587775
0.014	0.3948	0.2764	3.427	6.457	1.3529796	1.7847148
0.016	0.3958	0.4101	1.533	2.516	0.6067614	1.0318116
0.018	0.4311	0.3089	2.226	2.467	0.9596286	0.7620563
0.02	0.4091	0.3118	2.466	1.864	1.0088406	0.5811952
Average =					***1.0461816***	***0.88021135***

Table 2:*QPSK & 4QAM PERFORMANCE IN RAYLEIGH CHANNEL*

TIME	*QPSK BER*	*4QAM BER*	*QPSK SNR(dB)*	*4QAM SNR(dB)*	*QPSK(BER x SNR)*	*4QAM(BER x SNR)*
0.002	0.2736	0.1751	1.288	3.18	0.3523968	0.556818
0.004	0.3688	0.3506	2.288	1.175	0.8438144	0.411955
0.006	0.3814	0.3348	2.496	1.807	0.9519744	0.6049836
0.008	0.4091	0.3279	2.836	4.011	1.1602076	1.3152069
0.01	0.3887	0.3128	4.728	6.087	1.8377736	1.9040136
0.012	0.3854	0.3042	2.886	2.992	1.1122644	0.9101664
0.014	0.3869	0.3121	2.496	1.258	0.9657024	0.3926218
0.016	0.3921	0.3186	2.329	0.7314	0.9132009	0.23302404
0.018	0.4369	0.3221	2.27	3.501	0.991763	1.1276721
0.02	0.4333	0.3237	5.769	5.476	2.4997077	1.7725812
Average =					**1.16288052**	**0.922904264**

Table 4:*QPSK & 4QAM performance in Rayleigh vs. Rician channel*

TIME	*QPSK BER(Rayleigh)*	*4QAM BER(Rayleigh)*	*QPSK BER(Rician)*	*4QAM BER(Rician)*
0.002	0.2902	0.1743	0.2736	0.1751
0.004	0.3847	0.2692	0.3688	0.3506
0.006	0.4073	0.2807	0.3814	0.3348
0.008	0.3984	0.2746	0.4091	0.3279
0.01	0.4051	0.2885	0.3887	0.3128
0.012	0.3999	0.2815	0.3854	0.3042
0.014	0.3948	0.2764	0.3869	0.3121
0.016	0.3958	0.4101	0.3921	0.3186
0.018	0.4311	0.3089	0.4369	0.3221
0.02	0.4091	0.3118	0.4333	0.3237



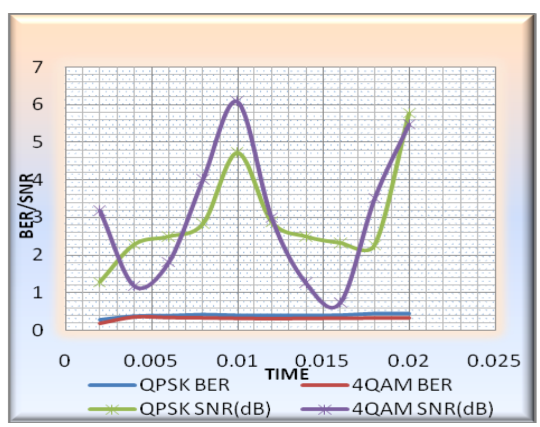


Figure 4*: BER/SNRQPSK & 4QAM performance in Rician channel*

Figure 3:*QPSK & 4QAM performance in Rayleigh channel*

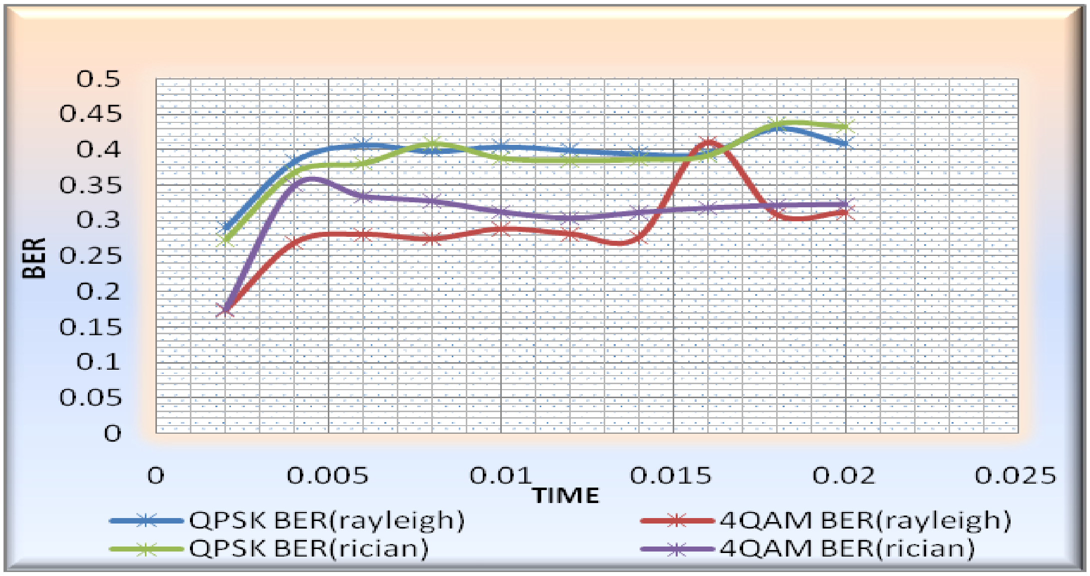


Figure 5: *QPSK & 4QAM in Rayleigh vs. Rician fading Channel*

Deductions made from the Research.

- That in both Rayleigh and Rician fading channels, the 4-QAM modulation scheme produces a higher signal to noise ratio (SNR) than QPSK scheme.
- That the BER for the 4QAM modulation scheme–for both Rayleigh and Rician fading channels– is lower than in the QPSK scheme.
- That the 4QAM scheme has a lower BER in Rayleigh fading than in Rician fading channel. The BER, however, increases exponentially with the transmission duration, between T = 0.014 and 0.016 particularly. At 0.016 the same 4QAM with the least BER at 0.002, produces the highest BER in Rayleigh environment.
- As indicated in the graphs, the 4QAM scheme maintained a more stable transmission trend in Rician channel than in Rayleigh fading channel. This is probably due to the destructive and constructive nature of the interferences as unique to Rayleigh fading environment.

Although 4QAM produces lower BER value than QPSK in Rayleigh channel, the impact of Rayleigh fading on the scheme is so much that it results in transmission instability. QPSK produces more stable transmission.

5.0 CONCLUSIONS

In telecommunication systems the 4QAM is a better modulation scheme than QPSK even with the disadvantage of noise/distorted signal demodulation challenge for QAM systems. 4QAM schemes perform better in Rayleigh fading environment than it does in Rician environment.

However, it does so at the cost of transmission stability. 4QAM schemes offer more stable transmission in Rician fading environment than in Rayleigh fading environment. In this paper, SNR/BER was sapplied in determining the performance of two similar modulation schemes with same information bits transmittable per symbol. The results and findings of this research are based on varying time period in the transmission of signals in Rayleigh and Rician fading environment, not fixed SNR. Based on this premise, the following conclusion about the QPSK and 4QAM modulation schemes are drawn.

QPSK perform better in Rician fading environment than in Rayleigh environment. Where the use of QPSK scheme is imperative, it should be applied in Rician environment for better signal quality.

Transmitted signals get de-amplified with distance as the signals experience more distortion and picks up more noise as the time taken from transmitter to receiver increases.

The data set; and results obtained from this work are satisfactory.

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